Baby diaper absorbent cores

Improved design to provide material savings

1. Introduction

The general trend in diaper core development over the last 20 years has been towards slimmer and lighter products; the diaper becoming steadily closer in looks and feel to the textile underwear that it replaces.

The external diaper changes, such as the move to elasticised ears and narrower chassis, have been well documented and can be adopted by diaper manufacturers by retrofitting with purpose made machinery. The more subtle changes inside the absorbent core are not as well documented and reported, and for many diaper manufacturers are much more difficult to quantify and hence design. The tests commonly used in the industry for regular quality monitoring do not give a clear enough picture of the core performance of the diaper, and thus the simplistic approach of increasing SAP content while reducing fluff content is often adopted, causing a significant drop in performance and user satisfaction.

Disposables Consultancy Service has now developed new tests and testing devices in order to provide a deeper understanding of the absorbent core performance of baby diapers and consequently a means of designing them more effectively. As a result of these tests, reductions in materials of as much as 30% can be achieved while retaining performance levels. This is a significant advantage for manufacturers in a high output industry where materials must be optimised in order to maximise profit margins.

2. Existing diaper absorption tests

It is not the intention of this article to describe the full array of tests and testing devices available to diaper manufacturers and their material suppliers. The main types of tests used by manufacturers for determination of the fluid handling can be outlined as follows:

a. Absorption test – A free swell absorption test consisting of soaking a diaper in a 0.9% saline solution for 15 minutes or longer and then hanging for a further two minutes to allow excess fluid to run off. A traditional test that is often recorded but rarely discussed since its accuracy relies to a great extent on careful handling of the saturated diaper and adds little to our knowledge of the ‘real life’ performance.

b. Centrifuge Retention test – The traditional centrifuge retention test is a useful quick check of SAP content in a high speed production environment, but does not give us directly relevant information on performance.

c. Retention under direct pressure – The most useful of the absorption tests, although commonly only carried out under one pressure (0.7psi, 4.8kPa) for all diaper sizes, thus not adequately reflecting the range of pressures applied to modern slim diapers.

d. Absorption speed, rewet, spread test. – A useful 3 in 1 test that gives an overall impression of the diaper absorbent core. The test results require careful interpretation since performance depends on the interrelationship of the 3 results rather than any individual result. It can lead to some confusion by variation of the insult levels and time periods as well as by incorrect interpretation of the results.

e. Mannequin tests- The most elaborate option and the most expensive. Useful for designing for fit and for viewing the flow of fluids in the diaper. However, it does not take into account the many shapes of babies and the important impact of the dynamic pressures applied in use.
f. **Other diffusion, wicking tests** – Many tests have been developed using moisture detection sensors to map the spread of fluid, speeds of absorption and spreading on horizontal or curved surfaces.

3. **Testing Rationale**
   
The aim of the new group of tests is to assist the diaper designer in achieving a better understanding of the absorptive performance of the modern slim diaper core and to set values to certain performance characteristics so that improvements can be quantified during the design process and monitored during manufacture.

   Existing tests do not reflect the “real life” fluid storage and redistribution that occurs in the dynamic conditions of baby diaper usage; nor do they demonstrate the true differences in diaper performance that test panels clearly indicate. They are ‘snapshots’ of performance taken at one level of loading that have little direct relationship to ‘baby’ loading. These new tests utilise a range of loadings that produce a ‘movie’ rather than a ‘snapshot’, so that the performance can be viewed under varying and/or repeated pressures.

   In formulating these tests it was regarded of primary importance that the testing regime should reflect more clearly the dynamic nature of the loading on diapers and yet remain as simple and clear as possible. A useful by-product of the tests has been the development of more descriptive diaper Performance Indicators (PI), values that can be recorded in tabular form and used for comparison and monitoring of the performance of radically different core structures.

4. **New Test Regime**
   
The tests are described under the headings of the three main characteristics of fluid handling that are to be simulated and measured, the three R’s of diaper design:

   a. **Retention**  
      
      *Test: Retention under incremental Pressure*

   b. **Rewet**  
      
      *Test: Rewet under incremental Pressure*

   c. **Redistribution**  
      
      *Test: Fluid Redistribution Test*

The Maximum Design Pressure for each diaper size was first considered and it was calculated as the maximum pressure applied by a baby at the top limit of the specified baby weight range, as it is clear that the loading on an Extra Large/Junior diaper will not be the same as the loading on a Small/Mini size. The assumptions made in the calculation of these pressures are shown below for each size and, although these baby weight ranges can vary from brand to brand, the following are felt to be representative of the majority of diapers worldwide.

(The Maximum Design Pressure (MDP) used in all sample tests shown throughout this article is that of the Large/Maxi diaper.)

   a. Small/Mini 5kPa (0.725psi) Based on 6kg over area 10x10cm = 5.9kPa
   b. Medium/Midi 7.5kPa (1.09psi) Based on 10kg over area 12x10cm = 8.2kPa
   c. Large/Maxi 10kPa (1.45psi) Based on 15kg over area 12x12cm = 10.2kPa
   d. X Large/Junior 15kPa (1.81psi) Based on 22kg over area 12x12cm = 15kPa
A major innovation with the new tests is that the diaper is not just tested at one pressure, but at all pressures leading up to the MDP. In this way it is possible to predict the effect of smaller babies or less dynamic loads on the diaper.

a. Retention
The ‘Retention under incremental pressure’ test is used to determine three diaper characteristics- (i) overall retention, (ii) released fluid percentage and (iii) zoned retention. The diapers are soaked in saline solution for 15 minutes and then subjected to increasing levels of pressure; the fluid release is recorded at each pressure level and from this the retention of the diaper at each level is calculated.

i. Overall retention – The results of the retention test are plotted on Chart 1 as a linear graph of the relationship between the retained fluid in the diaper and the applied pressure; in this case for two different diaper types. The differing gradients in this case give a clear indication of the SAP characteristics contained within the two diaper cores. The retention at zero pressure level is not recorded in order to avoid the inaccuracies of handling that occur with such a highly saturated diaper (as mentioned in Section 2a above). This is a useful chart in itself, providing a method of approximating the diaper SAP content (as was the case with the centrifuge retention test) and also showing the differing relative absorptions of these two cores under increasing pressure. The test results will also be used to help in creating visually informative charts showing fluid diffusion and redistribution (see Chart 7 below). The theoretical capacity of the diaper samples can be read directly from this chart for the relevant MDP’s or for any other pressure that the designer may feel is appropriate. For example, the theoretical capacity of the Large size diapers shown in this chart are 420mls for Sample A and 393mls for Sample B at MDP of 10kPa. (The capacity is referred to as theoretical since it assumes a maximum pressure applied evenly over all zones of a fully saturated diaper).

ii. Released fluid percentage
The second characteristic calculated from the results of this test is the percentage of fluid that is released from the diaper under pressure. This, to a large extent, is determined by the SAP characteristics. This property has a significant impact on the rewet and redistribution performance.
The percentage is based on the release of fluid between 2.5kPa and the Design Pressure (DP) of the diaper and is calculated in the following way:

\[
\text{Released Fluid \%} = \frac{\text{Retention at 2.5kPa} - \text{Retention at DP}}{\text{Retention at DP}} \times 100
\]

For the two samples shown in Chart 1, these values are 31\% for Sample A and 11.9\% for Sample B. This percentage gives a good understanding of the amount of free fluid that will be moving around the diaper when pressure is applied and provides a P.I. that represents an important characteristic of the SAP within the core.

iii. Zoned Retention

The third output from the Retention test is the zoned retention bar chart at MDP. The diapers are loaded up to the MDP and then cut into 8 equal zones. The pieces are weighed and the fluid retention is calculated and recorded. The resulting Chart 2 is then drawn to show the retained fluid per zone.

The chart clearly shows the amount of fluid that this diaper will contain in each zone at the MDP, which represents the minimum retention that should be expected in each zone of the diaper in real life usage (since the MDP is set at the upper limit of pressure expected for this size of diaper).

This chart is useful when comparing different diaper cores in that it shows both the absorption profile and the theoretical retention capacity per zone.

Furthermore, using Charts 1 and 2, it is possible to quickly and easily produce predictive models that will closely reflect ‘real life’ retention performance as described in the following examples.

Examples

The two night time sleeping positions chosen below in Charts 3 and 4 are of a female baby sleeping on her back and a male baby sleeping on his front. (Above the age of 1 year, when SIDS is no longer a danger, it is quite common for babies to turn and sleep on their front. The boy on front position is the most difficult to combat since the leakage path to the front waist is so short).

In both cases the 10kPa retention (MDP) values have been used for the front and back zones and the 5kPa values (calculated pro-rata from Chart 2 using Chart 1 values) have been used in zones 4 and 5, since these zones of the diaper are unlikely to be subjected to the same body pressures as the front and back zones.
The results for this particular diaper core are 258mls for a girl baby facing up and 212mls for the boy baby facing down. If the diaper designer wishes to predict the capacity of the diaper for babies that are not at the maximum weight in the size, then it is a simple exercise to pro-rata the zoned profile of Chart 2 using the values obtained in the retention test and shown in Chart 1. These models are particularly instructive when interpreting test panel results or customer complaints, so as to better understand if the diapers have reached their real potential capacity for a particular sleeping position and a known baby weight.

b. Rewet

Industry standard rewet tests use filter paper, tissue paper or collagen film to measure the wetness of the diaper surface under a specified load. The new tests approach this characteristic in a more flexible way, similar to the Retention test, in that the diapers are tested under increasing pressures for each level of fluid content. In the Rewet under incremental pressure test, the samples are prepared in the same way as a horizontal rewet test with insults of saline solution being applied without pressure. The absorption speeds of each insult are recorded to provide a Performance Indicator for this characteristic.

At fluid levels of 100, 150, 200, 250, 300mls, samples are tested to record the percentage of saturation of the diaper surface under each pressure; these surface saturation percentages are then charted against the applied pressure. (In practice, with test experience, 2 or 3 critical fluid levels only will need to be tested for each diaper)

Chart 5 is a typical linear graph showing the rewet results of 3 samples of the same diaper, each containing different levels of applied fluid 150, 200 and 250mls. Rewetting of the
surface layer occurred at each of these fluid levels within the tested pressure range of 2.5 – 25kPa. At fluid levels below 150mls no surface rewet was exhibited.

From the particular sample shown in Chart 5 the following observations can be made about the diaper:

- The diaper will not suffer surface rewet with a 150ml fluid insult at normal working pressures.
- At the 200ml fluid content, the diaper surface will start to suffer rewet at 5kPa and will reach 25% surface rewet at MDP of 10kPa.
- At the 250mm fluid content, the diaper surface will be dry for pressures up to 5kPa and then become fully saturated at 10kPa. So, in real life terms, if the baby is lying down without overaggressive movement the diaper will feel dry (5kPa), if the baby sits in the wet area or moves with some impact then the surface will become wet (10kPa). This 250ml fluid level is described as the Critical Fluid Content (CFC) for this diaper, which is defined as the lowest fluid content level at which the surface becomes 100% saturated within the MDP range.

Using this visually descriptive chart, the designer can observe the rewet values at each step in pressure and can decide if surface rewet is occurring at too low a pressure. If so, the curve can be moved by altering the SAP quality and/or quantity, the fluff/SAP ratio or perhaps by changing the acquisition layer (ADL).

In Chart 6 the same ‘Rewet under incremental pressure’ test was used to compare the rewet performance of three different ADL’s on a diaper core. In this case the three curves are for the three different ADL densities with only one fluid quantity, the CFC level of 200mls in this case.

The first (blue) ADL sample was a 25gsm nonwoven, the second (pink) was a 40gsm TAB material and the third (yellow) contained both of these materials. The characteristic shifting of each curve to the right with increasing ADL gsm provides a clear picture of the effectiveness of each in moving the dry performance to higher pressure levels, thus ensuring dry skin for the baby in the ADL zones at higher weight and activity levels.

With this information to hand, the designer can have much more confidence in his ability to balance the advantages in diaper performance against the extra cost of heavier and bulkier ADL materials.

Note: The above surface rewet should not be confused with the internal dampness within the ADL and coverstock laminates. This latter “damp feel” tends to increase with increasing ADL weight and bulk. This characteristic is measured separately.
c. Redistribution

Having achieved an understanding of the pressure required to create surface rewet, it is then important to determine if this wetting of the skin will occur once or at every subsequent application of pressure. The rewet defined in 4(b) above will be referred to as the initial rewet. Subsequent pressure applications will occur in use as the baby moves around and it will be important to determine if the skin is going to be wet again with each movement or if the diaper surface will quickly be dried by the redistribution of fluids under pressure within the core. This information is produced from the results of the Fluid Redistribution test.

Firstly, in order to better visualise the effect of this test on the fluid inside the diaper, a bar chart is created showing the zoned distribution of the fluid in the diaper at the CFC. Chart 7 illustrates the fluid distribution in the 8 zones of the diaper. However, in order to make it a more visually descriptive chart, the results of the zoned retention were used to calculate values for the fluid in each zone as a percentage of the maximum retention rather than as a weight or volume of fluid. The shaded area at the top of the chart thus highlights the fluid that will be released under the testing pressure since in this area the fluid content is greater than the maximum level that can be retained at that pressure. This percentage of fluid will return to the surface of the diaper as the Initial Rewet.

The Fluid Redistribution Test is carried out on the diaper at the Critical Fluid Content in order to determine how the rewet varies under a repeated 120mm x 120mm wide load (for Large diaper size) that is applied at the MDP of 10kPa centred on the point of fluid insult. The pressure is applied at each stage for a period of one minute, with a pause of one minute between each application. The surface saturation over an 80mm diameter circular area (centred on the fluid application point) was recorded for each pressure application.
Some typical results are shown in Chart 8 for three different diaper cores.

**Diaper 1** - The top (light blue curve) was a diaper with high SAP and low fluff content. In this case there was very little reduction in the surface wetness level over 8 repetitions of loading; so the baby’s skin will be heavily rewet each time the design pressure is applied.

**Diaper 2** - The middle (dark blue) curve was a diaper with a lower SAP/fluff ratio than Diaper 1, which has allowed some redistribution of the fluid and thus a gradual reduction in the surface wetness to zero over 8 – 10 repetitions.

**Diaper 3** - The lower (purple) curve was a diaper that achieved the highest level of redistribution of the 3 diapers tested. This diaper was completely surface dry after 4 applications of pressure, but even the reduction in surface wetness from the first to the second pressure application was substantial.

The most important point to be learned from the results of the Fluid Redistribution Test and the resulting Chart 8 is that a standard rewet test gives a very ‘one dimensional’ picture of surface wetness. Not only does it give the result at a single rewet load (commonly 0.7psi, 4.8kPa), but it also shows only the initial rewet.

The ability to redistribute fluids is an important diaper core performance property that adds significant value to the diaper, and the drier quality of a well designed core will be reflected in test panel results for daytime and night time use; reducing the incidence of wakeful babies and diaper rash, two key factors influencing consumers’ diaper selection.

In order to visualise the effects of redistribution within the diaper, a further zoned diffusion test was carried out on Diaper 3 after testing. From the resulting Chart 9 it can be seen that the fluid has been displaced from Zones 5 and 6 and moved to Zones 2, 3 and 8. (As the zoned diffusion is a destructive test, Chart 9 shows the results of an average of...
similar diapers before and after redistribution).

5. Performance Indicators

Using the results of the above testing regime, it is possible to describe the performance of each diaper core specification using a set of tabular values that have been mentioned throughout this article and are referred to as Performance Indicators (PI). This summarising of values as a result profile makes it possible to compare the outline results for several diapers without becoming overwhelmed by the amount of information from detailed charts and tables. Some typical results with explanatory notes are listed below in Table 1.

<table>
<thead>
<tr>
<th>Diaper</th>
<th>Weight</th>
<th>Retention</th>
<th>Release %</th>
<th>Speed</th>
<th>Critical Fluid Pressure</th>
<th>Redist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample A</td>
<td>35</td>
<td>393</td>
<td>11.9</td>
<td>0.66</td>
<td>250</td>
<td>10</td>
</tr>
<tr>
<td>Sample B</td>
<td>43</td>
<td>421</td>
<td>31.9</td>
<td>0.92</td>
<td>200</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Table 1

Retention - The value of the retention at Maximum Design Pressure (MDP) (Chart 1)
Release % - The release of fluid between 2.5kPa and MDP.
Speed – The speed of absorption of the 2nd insult of fluid in the rewet test. For Large diaper insults these are 50ml increments from 1st to 5th insult.
Critical Fluid Content & Pressure - The CFC is the lowest fluid level at which the diaper will reach full surface rewet within the MDP range. The pressure recorded is that pressure at which the diaper becomes 80-100% surface wet. This pressure will be less than or equal to the MDP.
Redistribution – The number of pressure applications before the diaper rewet value falls below 10%. If this value has not been reached at 12 applications then the value is recorded as 12+.

6. Conclusion

The tests, charts and PI’s described in this article provide the diaper designer with the information that is needed to design and monitor diaper absorbent cores. However, it is important that the mechanical properties of the core are also measured. At DCS, the Hardy Integrity Tester (HIT) device provides the data on this important design parameter, quantifying the strength of the absorbent core within the diaper envelope. There is little point in producing a highly absorbent core to retain and redistribute 300mls of fluid in the most effective way, without also ensuring that the distributive structure of the diaper remains intact long enough to allow this to happen. Wicking ability is also quantified and, when combined with the integrity results, is an important indicator in determining the optimum core density.

Another major parameter in the design process is the ‘fit’, which must be designed in such a way as to hold the diaper in a position that will allow the core to operate effectively and to prevent premature leakage at the legs or waist. The waist elastics, leg elastics and leg cuff will all have an impact on this performance parameter.

The three design factors of absorbency, strength and fit must be optimised in order to achieve the best possible overall diaper performance at the lowest possible price. The designer must also ensure that the materials used are ‘fit for purpose’ and that there are no obvious defects in the final diaper.
The writer feels that the new tests described in this article will now provide the diaper designer and manufacturer with the key information and measurements that are required to design today’s thin diaper cores. The test results finally provide ‘real life’ performance levels and can be used for direct comparison with test panel results, thus reducing the possibility of misinterpretation.